AD-A031 738   ARIZONA UNIV TUCSON
BEAM-FOIL SPECTROSCOPY.(U)
NOV 76 S BASHKIN

UNCLASSIFIED

1 OF 1
AD
A031738

END

DATE
FILMED

12-76

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
BEAM-FOIL SPECTROSCOPY	
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
Stanley Bashkin	N00014-75-C-0499

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
University of Arizona Tucson, Arizona 85721	

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Mr. Max Irving Room 421 Space Sciences Bldg. University of Arizona, Tucson, Arizona	November 4, 1976
	13. NUMBER OF PAGES
	Seven (7)

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
Dr. William Condell (Code 421) Office of Naval Research Arlington, Virginia 22217	Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DDC

RECEIVED

NOV 8 1976

B

DD FORM 1473 1 JAN 73   EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

20/8

* PARTICLE BEAMS
* FOILS (MATERIALS)
* SPECTROSCOPY
  KINETIC ENERGY
  DOPPLER EFFECT
  ULTRAVIOLET RADIATION
  SPECTRAL LINES
  IONIZING RADIATION
  VAN DE GRAAFF GENERATORS
  ENERGY LEVELS
  METASTABLE STATE
  QUANTUM ELECTRODYNAMICS
  ELECTRONS

No abstract

Elite ────────────────────────────► Pica ──►

Summary as of 1970. The method underlying beam-foil spectroscopy (BFS) and the main features of the beam-foil source were described in the 1970 Yearbook, pp. 117, 118. As of that time, the highest particle energy used was 20 MeV, the Doppler effect caused seriously degraded shapes of the spectral lines, few observations had been made in the extreme ultraviolet wavelength range, many spectral lines of unknown origin appeared, and the experiments were restricted to the emission of light from the excited particles. Advances have since been made in all the foregoing.

Particle energies. The higher the particle energy, the greater the number of electrons which are removed by the beam-foil interaction. Ions with but few bound electrons characterize hot plasmas, such as the solar corona or controlled thermonuclear reactors (CTR's) so the study of such ions gives basic information about plasma behavior. Moreover, the electrons in ions of high net charge move with relativistic speeds; the determination of the electron orbits and their decay rates in such ions offers a sensitive test of quantum electrodynamics (QED).

The highest energy achieved so far in a standard beam-foil experiment is now 110 MeV, used in an experiment on iron at Brookhaven National Laboratory's tandem Van de Graaff facility. Iron ions were detected with as many as 17 electrons removed; some of those ions have been seen in the solar corona and in CTR's. A new experiment on iron is planned to be done at 500 MeV, with the Super Hilac at Berkeley. A net charge of +23 will be produced in that work.

Marrus and collaborators have studied relativistic effects by producing ions from Si (+13) to Fe (+23). They are investigating the Lamb Shift, and have measured the decay rates for "forbidden" transitions, including the double electric-dipole decay mode. The measured decay rates are generally in good agreement with the predictions of QED, but there appears to be an anomaly in the results on Cl^{+15} and Ar^{+16}. Marrus' work differs from "standard" BFS experiments in that he detects soft x-rays with solid-state, non-dispersive systems, whereas "standard" experiments employ diffraction-grating spectrometers.

Doppler Effect. The spectroscopic quality of an experiment may be described in terms of the width of the spectral lines; broad lines may conceal blends of contributions from several sources. Because of the high speed (several percent of the speed of light) of the particle beams, the Doppler effect often produces line widths of 10 Å or more. That is unacceptable for precision measurements. Stoner and Leavitt showed that a spectrometer could be "refocused", i.e., have its slits or grating moved so that the Doppler-broadened lines are brought to a reasonably good focus. The Doppler width is roughly proportional to wavelength and, with refocusing, can be reduced to about 1 Å at 4000 Å. Further reduction in line width is presently limited by foil-scattering, but laser techniques (see below) might lead to further improvement.

Extreme Ultra-Violet. The more highly ionized a system, the greater the energy separation of the main electronic orbits, and the shorter the wavelengths of the transitions between orbits. Also, the rates of decay rise rapidly with increasing degree of

ionization so that the largest part of the decay power in ions of high net charge is associated with radiations of short wavelength. To examine those radiations, grazing-incidence spectrometers have been used with increasing frequency in BFS. Those instruments allow one to detect spectral lines as short as 40 Å; below 100 Å, curved-crystal, x-ray spectrometers have also been introduced into BFS.

Identification of Spectral Lines. Many of the "new" spectral lines of BFS have been identified as "Rydberg" lines. Such lines occur when an electron makes a transition out of a level of large principal quantum number, the orbiting electron being far from the nucleus and inner electrons which form the field which causes the transition to occur. One consequence of this arrangement is that the detailed structure of the inner electron cloud is relatively unimportant in dictating the nature of the transition, the single most significant factor being the net charge of the ion. Therefore all Rydberg transitions are much the same, independent of the element and the stage of ionization. The energies of Rydberg levels can be roughly calculated using theory originally created by N. Bohr to account for the atomic structure of hydrogen. New experiments are underway in which the Rydberg levels are created within a microwave region. By adjusting the microwave frequency until the microwaves are absorbed by one of the Rydberg levels, the energy separation of two neighboring Rydberg levels can be measured and compared with the predictions of sophisticated atomic theory.

Some Rydberg levels are shifted in energy from their Bohr values

because the orbiting electron polarizes the inner cloud of electrons. The dipole and quadrupole polarizabilities have been measured for a number of Rydberg levels in several elements excited in the beam-foil source.

Rydberg levels are quasi-degenerate in the orbital angular momentum, the quantum number for which is symbolized by "ℓ". The mean life of a level is a strong function of ℓ, generally becoming longer as ℓ becomes larger. The application of an electric field causes the several ℓ-states to "mix", one effect being to reduce the mean life of the excited system. The use of such a field with the beam-foil source has proved to be a convenient way of corroborating the Rydberg character of the excited states, for a reduction of a Rydberg level's mean life shows up directly as a marked change in the intensity of the emitted light.

A second source of the new spectral lines is "doubly-excited" levels, in which two electrons are simultaneously lifted out of their normal orbits but still stay bound to their parent nucleus. It frequently happens that the total excitation energy is then greater than the ionization energy needed to detach a single electron completely from its parent nucleus. However, selection rules may prevent that ionization from taking place. The result is that optical transitions occur between a doubly-excited level and another level of lower energy. Doubly-excited levels are generated prolifically in the beam-foil source, particularly for light elements in the He I and Li I isoelectronic sequences. Some such states have also been identified in Na I, Mg II, and Ca II.

New Developments. While the great majority of BFS experiments treat light, groups of electrons with well-defined energies also arise from the foil-excited particles. These Auger electrons give information about the electronic structures of complicated systems. Pegg and Sellin have shown that metastable configurations, involving core excitation, are not uncommon in three-electron ions from oxygen (5+) to argon (15+). These experiments, which include lifetime measurements, deal largely with forbidden transitions in which relativistic effects are important. As an example, consider the doubly-excited state (1s2s2p) $^4P^0_{5/2}$. Comparison of experiment and theory for the decay rate indicates a disparity which increases fairly rapidly with nuclear charge. It is interesting that the difference reflects measured decay rates which exceed the calculated ones. In optical BFS lifetime work, the discrepancies between measurement and theory are usually in the opposite sense.

Some of the metastable levels seen in this Auger-electron work have also been detected in BFS experiments on x-rays.

An electronic level can be characterized by several numbers, among them, the total angular momentum quantum number, J. Each level contains (2J + 1) states. In ordinary light sources, those states are equally populated, but in the beam-foil source they are distributed non-uniformly. This "alignment" causes the emitted light to be linearly polarized; the polarization can be affected by an external magnetic field. Measurements of the polarization as a function of magnetic field give information on the Landé g-factor, and can also be used to determine lifetimes independent

of the line-blending and cascade-repopulation problems which enter

into standard lifetime experiments. Furthermore, hyperfine ef-

fects can also be studied because of the imbalance mentioned above.

Usually the excited foil is perpendicular to the particle beam.

However, tilting the foil introduces a new feature into the emit-

ted light, which is now circularly polarized. This circular po-

larization reflects the "orientation" of the excited state, i.e.,

the total angular momenta of a large fraction of the particles all

point in the same direction. Orientations of 50% or more have

been reached by reflecting a beam of ions from the polished sur-

face of a solid, the effects being enhanced at grazing-incidence.

Some recent work has involved sending a laser beam across the

beam of excited particles. The laser wavelength can be Doppler-

shifted so as to coincide with the wavelength of a transition be-

tween some foil-excited level and a higher one. The decay of the

upper state can then be monitored by means of different transi-

tions. This technique promises to produce spectral lines with

much smaller widths than can now be obtained. In addition, life-

times determined for the upper states should be free from both

line-blending and cascade-repopulation effects.

Numerous lifetime measurements have now been reported for a wide

variety of levels, stages of ionization, and elements. Two major

applications of these results have been made to astrophysics and

to theory. In astrophysics, the intensity of a spectral line as

seen by astronomers is proportional to the number of source atoms

(or ions) and to the lifetime of the relevant excited level.

Whaling and collaborators have measured the lifetimes of a number

of levels in Fe I and Fe II. From their data, they showed that the iron content of the sun is some ten times higher than earlier data had suggested. This finding, which has been corroborated by related work on non-beam-foil light sources, has major consequences for the theory of the evolution of the chemical elements.

Beam-foil lifetime data are now sufficiently numerous that they can guide theorists along the correct calculational lines; conversely, the calculations serve as indicators of which experiments should be carried out or redone.

Bibliography: Topics in Current Physics: Beam-Foil Spectroscopy, ed. S. Bashkin, Springer-Verlag (Heidelberg, 1976); H. J. Andrä, Physica Scripta 9, 257 (1974); I. Martinson and A. Gaupp, Phys. Reports $15C$, 113 (1974); H. G. Berry, Physica Scripta 12, 5 (1975).